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# Experience in the Use of a Strain-gauge Pressure Transducer for Comparison in Liquid Media up to 600 MPa between the NIST and the IMGC

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**Abstract**. Primary standard piston gauges are frequently used to perform pressure comparisons, but at other times, and particularly in the pressure range greater than 300 MPa, suitable transfer standards are used for the same purpose. The IMGC and the NIST have completed a bilateral intercomparison for gauge pressure measurements in liquid media up to 600 MPa using a strain-gauge pressure transducer as the transfer standard. The main metrological characteristics of the transducer are discussed, particularly the stability with time and the uncertainty limits for use as a transfer standard. The pressure scale between 100 MPa and 600 MPa as maintained by the two laboratories is described, and the results of the comparison are discussed in order to demonstrate the agreement in pressure measurement between the IMGC and the NIST.

## 1. Introduction

Within the framework of the metrological cooperation between Italy and the USA, a pressure intercomparison in liquid media from 100 MPa to 600 MPa has been performed between the IMGC and the NIST.

The purposes of this intercomparison were to compare the agreement of the pressure scale from 100 MPa to 600 MPa as maintained by the two laboratories and to evaluate the metrological performance of a gauge pressure transducer as a transfer standard in order to understand its limits and the specific measurement procedures that need to be adopted. Earlier cooperative studies suggested the use of the strain-gauge transducer as a transfer standard for this comparison [1].

The primary pressure standards maintained by the two laboratories are of different types. The NIST primary standard is a controlled-clearance piston gauge for measurements up to 650 MPa. The IMGC standard is a free-deformation piston gauge for measurements up to 600 MPa.

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## 2. The NIST Primary Standard

The piston and the cylinder of the NIST primary standard are made of tungsten carbide; the piston has a nominal diameter of 3 mm. The piston-cylinder is a commercially available unit adapted to fit into an existing base. The piston gauge is equipped with a Bourdon tube gauge for measuring the clearance-controlling pressure, a capacitance sensor to measure the vertical position and fall rate of the piston, and a thermistor to measure temperature. For this project the pressurizing fluid was a mixture of two parts heptane to one part mineral oil by volume. The piston gauge was characterized by dimensional measurement of the piston diameter, by determination of the appropriate values of the clearance-controlling pressure through piston fall-rate measurements, and by measurements of the pressure distortion coefficient of the cylinder with the aid of a sensitive InSb pressure transducer [2].

## 3. The IMGC Primary Standard

The IMGC primary standard used in this intercomparison is a free-deforming (simple) piston gauge. The piston is made of hardened tool steel and the cylinder is of tungsten carbide. The nominal diameter of the piston is 1,6 mm. The effective area was determined by cross-floating against other lower pressure primary

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standards. The piston gauge is equipped with a platinum resistance thermometer and a device for the visualization of the piston fall rate and position. The pressure coefficient of the piston-cylinder unit was determined by means of a combined theoretical/experimental study [3]. The fluid used was di-ethyl hexyl sebacate.

## 4. Transfer Standard and Procedure

A strain-gauge pressure transducer provided with signal conditioning and a digital readout (in pounds per square inch, psi) was used as the transfer standard. The signal conditioner allowed zero and span adjustments. The least-significant digit of the readout is 70 kPa (10 psi) which we took to be the resolution limit of the instrument. It has a pressure range of 700 MPa and is compensated for the temperature range between 16 °C and 71 °C.

The main limitation of this kind of pressure transducer is hysteresis which can be as high as 3 % of the pressure reading. Figure 1 is a plot of hysteresis for two different transducers of the same make and model as used in the present comparison. The hysteresis is expressed as the transducer reading in the decreasing pressure cycle minus the transducer reading in the increasing pressure cycle divided by the pressure measured by the piston gauge. Hysteresis error was avoided in the present comparison by taking calibration data with monotonically increasing pressure only.

For our measurements a simple procedure was followed:

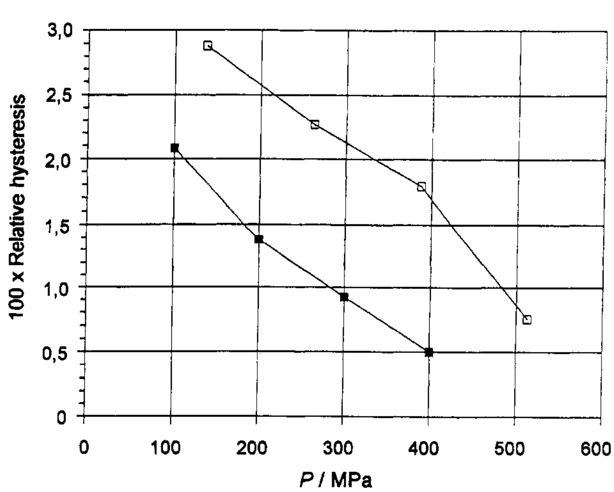


**Figure 1.** Hysteresis for two strain-gauge pressure transducers of identical make and model. The transducer represented by the filled-in squares was tested up to 500 MPa. The transducer represented by the open squares was tested up to 637 MPa.

(a) Allow about 1 hour for warm-up and stabilization of the electronics.
(b) Allow about 5 minutes for stabilization of the pressure before recording the transducer reading.
(c) Use only monotonically increasing pressure for the calibration cycle.
(d) After recording the reading for the maximum pressure, slowly reduce the pressure to zero.
(e) After the pressure is reduced to zero, the transducer is read at intervals for several minutes to be sure that the zero shift is not a function of time.
(f) Reset the zero on the signal conditioner at the start of each pressure calibration cycle.

During all of the calibration cycles at the NIST and the IMGC, the temperature of the transducer was between 19 °C and 24 °C which had negligible influence on the pressure measurements due to the thermal compensation.

## 5. Results and Discussion

This intercomparison was designed to be of the A-B-A type; the transducer was to be calibrated at the NIST, then at the IMGC, and then again at the NIST. Unfortunately, before the second set of calibrations at the NIST could be done, the NIST primary standard suffered a ruptured cylinder which destroyed the standard.

The initial calibrations were carried out at the NIST with six calibration cycles in January 1990 and two calibration cycles in June 1991. The nominal pressures were 137, 262, 388, 513 and 638 MPa measured with the NIST primary standard piston gauge and the procedures outlined above. The calibration equation that best describes the data of all eight calibrations taken as one data set is the third-order polynomial

$$p(\mathrm{NIST})/\mathrm{MPa} = 1{,}007191\, R/\mathrm{MPa} + 1{,}25028 \times 10^{-5} (R/\mathrm{MPa})^2 - 3{,}34990 \times 10^{-8} (R/\mathrm{MPa})^3, \qquad (1)$$

where $p$(NIST) is the pressure measured by the NIST piston gauge and $R$ is the corresponding pressure read by the transducer. The tripled standard deviation of the residuals of (1) is 0,137 MPa, which is equivalent to 215 ppm* at the maximum pressure. The residuals of (1) are plotted as a function of pressure in Figure 2. A different symbol represents each calibration cycle. The residuals are randomly distributed, which demonstrates the stability of the transducer over the eighteen-month period. Had the calibration changed over that length of time, then we would be able to distinguish between the residuals from the 1990 and the 1991 calibrations.

The transducer was hand-carried to the IMGC in December 1991 where six calibration cycles were done in March 1992. The nominal pressures were 100, 200,

* 1 ppm ≡ $1 \times 10^{-6}$.

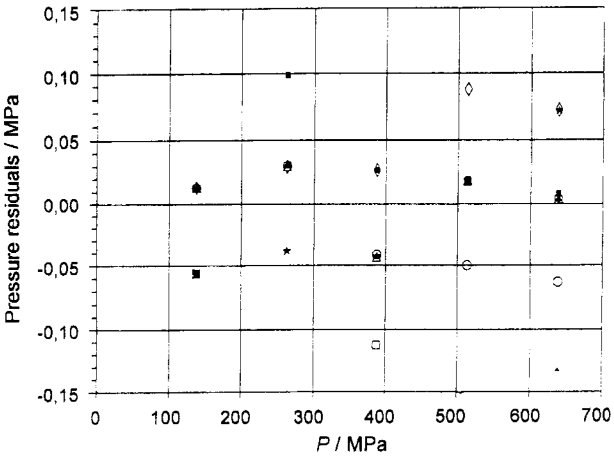


**Figure 2.** Residuals of (1) plotted as a function of pressure. A different symbol represents each calibration cycle. The distribution is random.

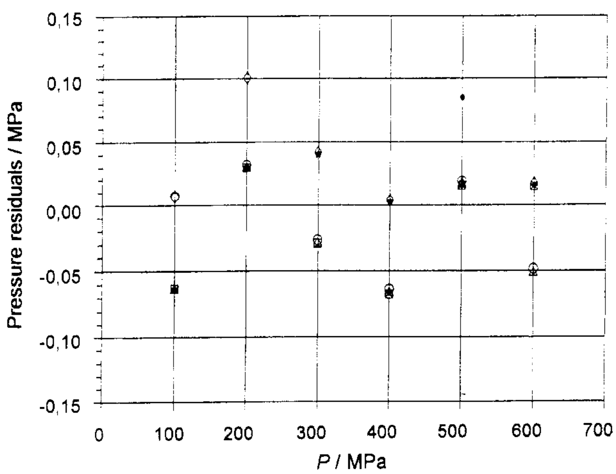


**Figure 3.** Residuals of (2) plotted as a function of pressure. A different symbol represents each calibration cycle. The distribution is random.

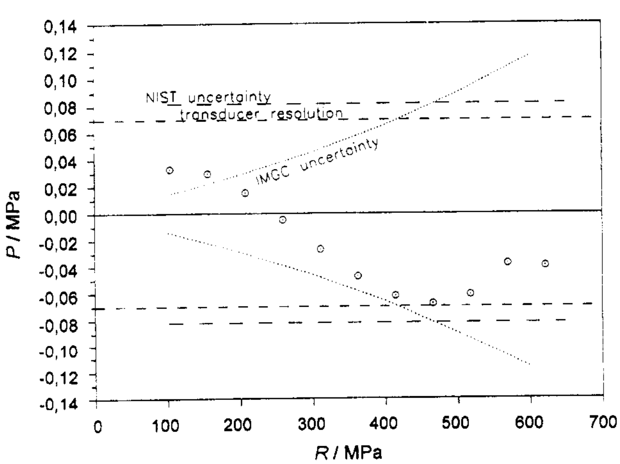


**Figure 4.** Differences in pressure calculated from (1) and (2) for arbitrary values of $R$/MPa represented by dotted circles, transducer resolution, and 3 $\sigma$ uncertainties of the IMGC and NIST primary standards, all plotted as a function of pressure.

300, 400, 500 and 600 MPa measured by the IMGC primary pressure standard piston gauge. The calibration equation that best describes the IMGC data is the third-order polynomial

$$p(\mathrm{IMGC})/\mathrm{MPa} = 1{,}007\,872\ R/\mathrm{MPa} + 8{,}636\,25\times10^{-6}(R/\mathrm{MPa})^2 - 2{,}901\,19\times10^{-8}(R/\mathrm{MPa})^3, \qquad (2)$$

where $p$(IMGC)/MPa is the pressure generated by the IMGC piston gauge. The tripled standard deviation of the residuals of (2) is 0,127 MPa, which is equivalent to 212 ppm at the maximum pressure. The residuals of (2) are plotted as a function of pressure in Figure 3, where a different symbol represents each calibration. Again, the distribution is random.

In order to compare the results obtained at the IMGC with those at the NIST, we calculated [$p$(IMGC) – $p$(NIST)]/MPa for a series of arbitrary, evenly spaced values of $R$/MPa, spanning the range from 100 MPa to 600 MPa, which are plotted as a function of pressure in Figure 4. The figure also shows lines defining the limit of resolution of the pressure transducer and the uncertainties (3 $\sigma$) of the IMGC and the NIST primary standards.

All the values of [$p$(IMGC) – $p$(NIST)]/MPa are smaller than the 70 kPa resolution limit of the transducer.

The uncertainty of the NIST primary standard is larger than the transducer resolution limit. Below 420 MPa the uncertainty of the IMGC primary standard is smaller than the transducer resolution limit. In this region, this pressure comparison is limited by the transducer resolution and nothing can be inferred regarding agreement within the IMGC uncertainty. Because the residuals of both (1) and (2) are random and without structure, and because all the data in Figure 4 lie within the resolution limit of the transducer, the apparent structure of [$p$(IMGC) – $p$(NIST)]/MPa in the plot has no significance.

Based on these measurements, we conclude:

(a) The transducer calibration equations based on the two primary standards in this intercomparison agree in the pressure range between 100 MPa and 600 MPa to within 70 kPa, which is the limit of resolution of the transducer. At the high-pressure end of the range, which is the central interest of this intercomparison, the transducer resolution can be expressed as 117 ppm.

(b) This intercomparison is limited by the resolution of the transducer. This is particularly evident at lower pressures where the uncertainties of the IMGC primary standard are significantly smaller than the resolution of the transducer. This situation would certainly have been improved had an appropriate high-pressure piston gauge been available for a transfer standard.

## References

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2. Bean V. E., *BIPM Monographie 89/1*, 1989, 125-131.
3. Molinar G. F., Barbera B., Bianchi L., Cresto P. C., and Maghenzani R., *High Temp.-High Press.*, 1992, **24**, 259-265.